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DEVELOPMENT OF AN ENCAPSULATED
THERMIONIC POWER GENERATOR

QUARTERLY TECHNICAL PROGRESS REPORT
FOR THE PERIOD
NOVEMBER 1 THROUGH JANUARY 31, 1963

Contract AF33(657)-10077
Project Number: 8173
Task Number: 817305-20

Prepared for:

Aeronautical Systems Division
Air Force Systems Command
U. S. Air Force
Wright-Patterson Air Force Base, Ohio

Prepared by:

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Nuclear Division
Baltimore 3, Maryland

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MND-2945-1

The work covered by this report was accomplished under Air Force Contract AF33(657)-10077, but this report is being published and distributed prior to Air Force review. The publication of this report, therefore, does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published for the exchange and stimulation of ideas.

INTRODUCTION

This program, Development of an Encapsulated Thermionic Power Generator, Contract AF33(657)-10077, is designed to performance test and evaluate a two-converter thermionic generator containing fuel bearing emitters. In addition, fuel elements with dimensions comparable to those of the emitters will be thermally endurance tested. Progress achieved thus far includes initiation of fabrication of several generator components and fabrication of a fuel element and its vacuum test chamber.

SUMMARY

PRESENT WORK

The engineering design of the double diode thermionic power generator has been completed. Fabrication of several component parts has been initiated. The parts for the fueled emitters are almost completely fabricated with only assembly and final machining remaining. The manufacture of other generator components including the collector temperature control assembly and the ceramic-to-metal seals has been initiated.

The engineering design of the clad fuel elements has been completed and the first element, similar in configuration to the fueled emitter, has been fabricated. This element will be used to determine the changes in the vacuum emission characteristics over a 200 hour test period. The vacuum test chamber has been fabricated and is undergoing preliminary outgassing.

FUTURE WORK

During the next reporting period, fabrication of the fueled emitters will be completed. Fabrication of the remaining generator components and the back-up device will continue. The vacuum emission test will be conducted and the remaining fuel elements for the 200-hour endurance test will be fabricated and a pre-test examination performed.

TECHNICAL DISCUSSION

I. Fabrication of the Fueled Clad Double Diode Thermionic Generator

The engineering design of the double diode thermionic generator containing fuel bearing emitters has been completed. An assembly drawing of the device is shown in Figure 1 (Martin Drawing No. 390-0790116, Sheet 1). The device has been given the Martin designation FDM-1. During this reporting period, the fabrication of some of the FDM-1 components was initiated. These efforts are described below.

A. Fueled Emitter Fabrication

Fabrication of the fueled emitters was begun in January. A minor design change in the end cap of the top cathode was made during this quarter and is reflected in Figure 1. The end cap of the upper cathode was redesigned to provide a ductile lip for crimping to the intermodule electrical lead. The redesigned end cap consists of a 0.146 inch tantalum plate bonded to the exterior face of a 0.020 inch molybdenum plate. A bi-metallic end was resorted to in order to maintain a continuous molybdenum barrier for the uranium dioxide-molybdenum cermet fuel while simultaneously providing a ductile lip for crimping to the anode lead of the next diode.

Exploratory development work showed that this bi-metallic end cap could be made by hot press bonding a disc of tantalum to a disc of molybdenum - 1/2% titanium alloy, and then machining the resulting bi-metallic slug to the diameter and thickness required for the fueled emitter fabrication operation. The hot press bonding operation required to produce a satisfactory metallurgical bond between the two metals was a three (3) minute hold at 2150°C under a pressure of 5000 psi in a graphite die. This time-temperature relationship required the use of a flame sprayed zirconium oxide protective coating on all exterior surfaces of the discs to prevent excessive carbide formation on the surfaces. Figure 2 is a photomicrograph of the interface between the tantalum and molybdenum - 1/2% titanium alloy discs and illustrates the degree of bonding attained in this operation.

Fabrication of the component parts for both the upper and lower cathodes is now being completed. These parts include the cermet fueled bushing, center mandrels, exterior cladding sleeves, bi-metallic end caps for the top cathode and the standard end caps. The next phases of the program are fitting and assembling of the components into the fueled emitter configuration, flame spraying of the exterior surfaces with zirconium oxide, and hot pressing the assembly into fueled emitters. These fabrication operations will be followed by radiographic inspection, final machining, and incorporation in the generator assembly.

B. Fabrication of Other Generator Components

Work was initiated on the fabrication of components for the collector temperature control assembly. This assembly permits variation of the collector temperature so that its effect on thermionic performance may be investigated. These parts are similar in nature to those used successfully in past Martin devices and for which elaborate manufacturing procedures have been established.

Components for the ceramic-to-metal seals are being manufactured. It is expected that the seals will be assembled during the month of February. Procedures for the seal component manufacture and assembly have been standardized. Past experience with these seals has been excellent. One seal operated successfully in a device for over 2000 hours and showed no sign of deterioration at device failure.

During the next quarterly period, fabrication of components for the FDM-1 and its back-up components will continue.

II. Evaluation of Clad Fuel Elements

The engineering design of the clad fuel elements has been completed and an assembly drawing is shown in Figure 3 (Martin Drawing No. 390-0790122). The progress achieved during this reporting period in this portion of the program is described below.

A. Fuel Element Fabrication

Fabrication of the fuel element to be used to determine quantitative changes in the thermionic emission properties over a 200-hour test at design temperature has

been completed. This vacuum emitter element is similar in configuration to the fueled thermionic emitter with the following exceptions: the fueled section is 0.104 inches thick (with an equivalent U-235 density of 6.75 grams/cc) and the pellet has a 1/8 inch diameter through hole drilled concentric with the long axis. The purpose of this hole is to permit heating of the element in a vacuum chamber by the use of an electron bombardment heater that passes completely through the element. The fueled section of this vacuum emitter pellet is provided with a .040 inch inner cladding of molybdenum - 1/2% titanium to extend heater life and obtain more uniform heating of the fueled section.

Radiographs of the vacuum emitter after the hot press fabrication operation showed it to possess good quality metallurgical bonding between all components. Radiographs taken upon completion of the mandrel drilling operation and surface finishing operation revealed no loss of bond integrity due to the drilling or machining operations. Each radiographic operation was conducted using three 120° rotations about the long axis of the emitter in order to ensure complete coverage. The radiographs are not included in this report because of their poor reproducibility. Figure 4 shows the fueled vacuum emitter after completion of all fabrication operations.

During the next quarterly period, the fuel elements for the 200-hour endurance test will be fabricated and a pre-test examination conducted.

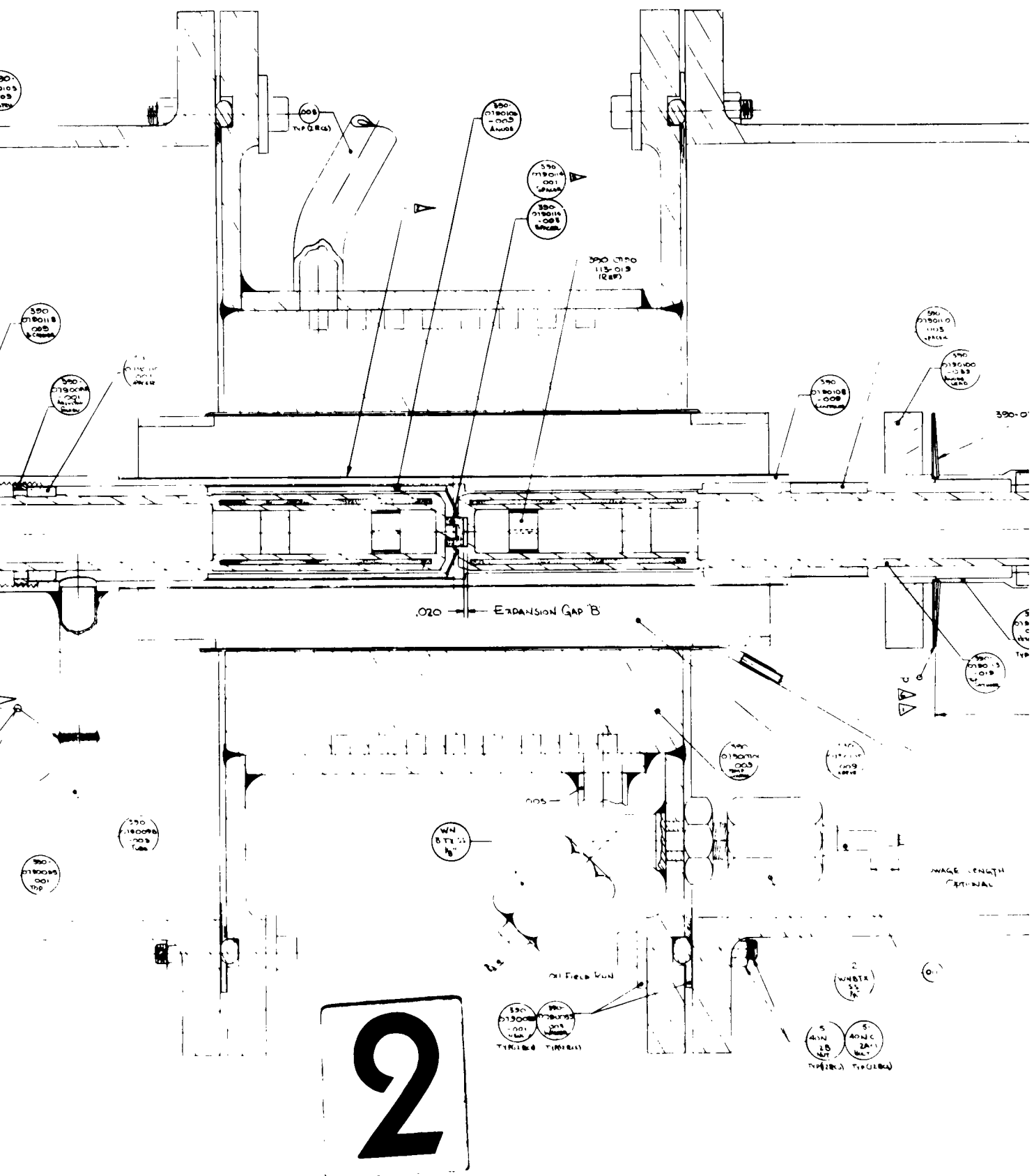
B. Vacuum Emission Test

In order to observe possible changes in the vacuum thermionic emission properties of a refractory metal clad fueled emitter, a vacuum test chamber has been fabricated and is undergoing preliminary outgassing. The test chamber is a water cooled metallic tube which will provide a high vacuum environment in which the fueled emitter element will be heated by electron bombardment. The 15 cm² fueled emitter will be heated to 1600°C and a cylindrical guard ring anode structure will be used to draw saturated thermionic emission current. After brief preliminary operation in the range of 1450 to 1700°C to determine the emission characteristics and thermal characteristics of the emitter structure (with respect to temperature gradients), the emitter will be operated for 200 hours at 1600°C. During this

time the output current will be monitored and periodic checks will be made of the thermionic emission characteristics. At the completion of the 200-hour test, a metallurgical examination will be conducted to determine the extent of any structural changes.

In making the emission measurements, particular care will be taken to insure that the emitter structure is operated at a constant temperature and that any effects of the diffusion of fuel constituents are detected. The diffusion of low-work function materials such as uranium metal or uranium dioxide to the surface is expected to greatly enhance the vacuum emission of the molybdenum - 0.5% titanium surface. If, on the other hand, diffusion takes place along grain boundaries and the fuel components evaporate from the emitter before a surface coverage is accomplished, then the influence on emission may be very small. Even if no change is seen in the thermionic emission, alpha radiation counters will be used to detect the presence of uranium compounds on the surface prior to metallurgical examination.

The effect which the presence of fuel material on the emitter surface will have on the performance characteristics of the vapor-filled converter is not clearly defined at this point. From thermionic considerations, materials which have high vacuum work functions have demonstrated superior performance in cesium vapor-filled converters. Hence the presence of low-work function fuel materials might be expected to lower the performance of the converter. This will be a point of particular interest in the vacuum emission test and in the prolonged operation of the fueled emitters in the FDM-1 device.





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- ▷ 6 • After Acquiring Top (Location Dim A) Make Top Seal Weld. Drive Adjustment (300-079008)
b) UNTIL (300-079014) BOTTOMS TURN REVERSE PROCEDURE TO ACHIEVE EXPANSION GAP "B".
Followed By The Final Seal - Weld In Assy.
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- ▷ 4 PART TO BE MATCH DRILLED AT ASSY. - 5-40NC-28X $\frac{3}{8}$
- ▷ 3 AL₂O₃ COATING SEE DWG 390-0790108-009.
- ▷ 1 BEFORE WELDING OR BRAZING CONTACT DON STOFFEL (DEPT 157) FOR INSTR.

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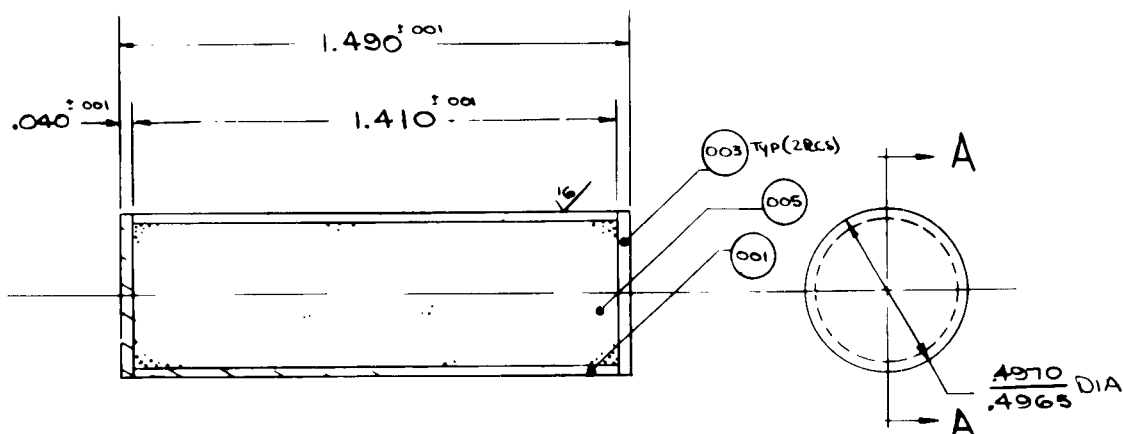
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FIGURE 1

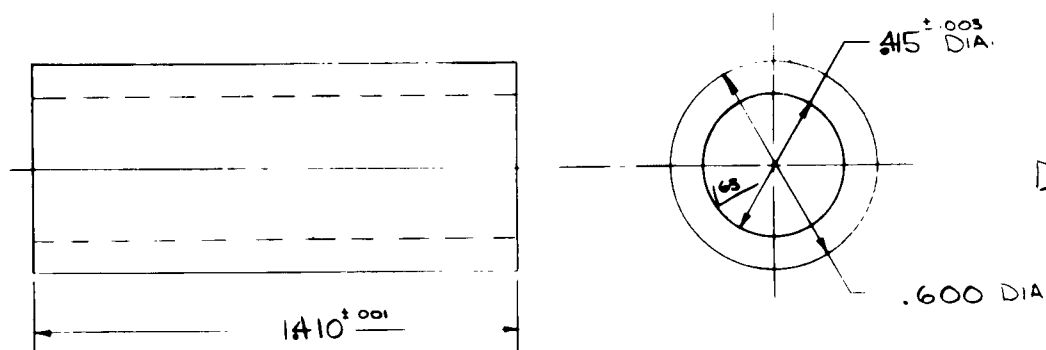


Figure 2

Bimetallic end cap of the top cathode of the FDM-1 device showing the bonding zone between the tantalum and the molybdenum - 1/2% titanium alloy. Hot pressed for 2 1/2 minutes at 5000 psi and 2150°C. Tantalum (on top) etched with mixed acids. Magnification: 400X

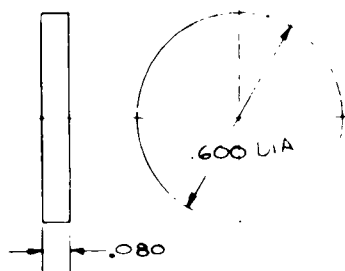


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1. FOR HOT F

DETAIL -001



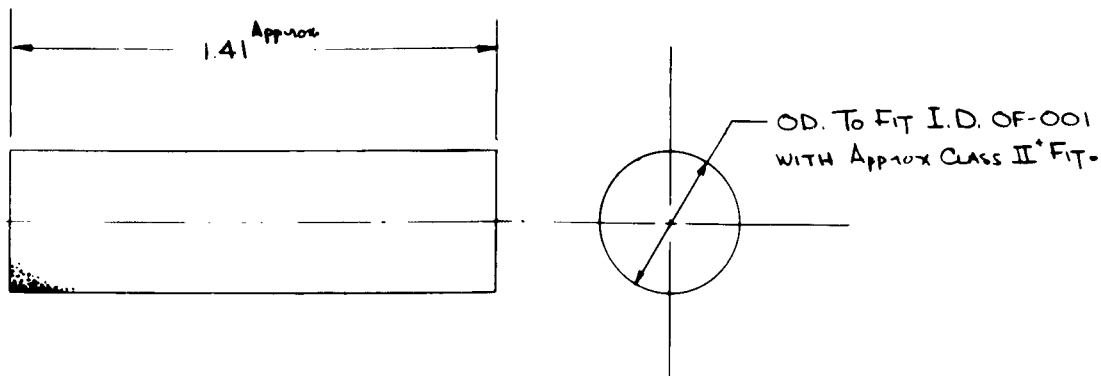
DETAIL -003

1

CALC		DASH	
WT		NUMBER	
		-009	39

390-0790122

SYN		REVISIONS		DATE	APPROVED
ZONE	DESCRIPTION				
A	ADDED 390-0790124			1-18-62	J. MONROE



DETAIL-005

- 2 ALL MACH SURFACES ¹²⁵✓ EXCEPT AS NOTED.
 1. FOR HOT PRESSING INSTRU. CONTACT J. MONROE (DEPT 1571).

2

-005		FUEL HO ₂ Mo COMP 65% Cu, 35% Mo		COMM
-003		END RUG 3/4" x 1/8" x 1/8"		COMM
-001		EMITTER SLEEVE 3/4" x 1/8" x 1/8"		COMM
-000		FUEL PELLET		

SYN	ZONE	DESCRIPTION	STOCK SIZE	MATERIAL OR VENDOR	FINISH OR MIP CODE	CMG
		UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND ARE AFTER PLATING				
		FRAC- TIONS .X XX XXX				
		+ 1/32 + 1 + .03 + .010 + 1/20				
		MACHINED SURFACES REF MIL-STD-10				
		MIL-I-8500 STATUS				
		INTERCHANGEABLE REPLACEABLE UNCONTROLLED				

DRAWN BY RE LOWRY 1654 12-27-62		DATE 12-27-62	
CHECKED BY J. P. HAN 12-27-62			
STRESS ENGR. BY ENGR.			
MAYL. ENGR. BY ENGR.			
RELIABILITY BY ENGR.			
PROGRAM REP. 12-27-62			
CUST. REP. W. P. HAN 12-27-62			

THE MARTIN COMPANY		BALTIMORE, MARYLAND	
FUEL PELLET ASS'Y. THERMIONIC MODULE CRP			
ONE IDENT NO.	SIZE		
38597	D	390-0790122	
SCALE 4/1	NUCLEAR DIV.	SHEET 1 OF 1	

FIGURE 3

390-020/3
390-024/4

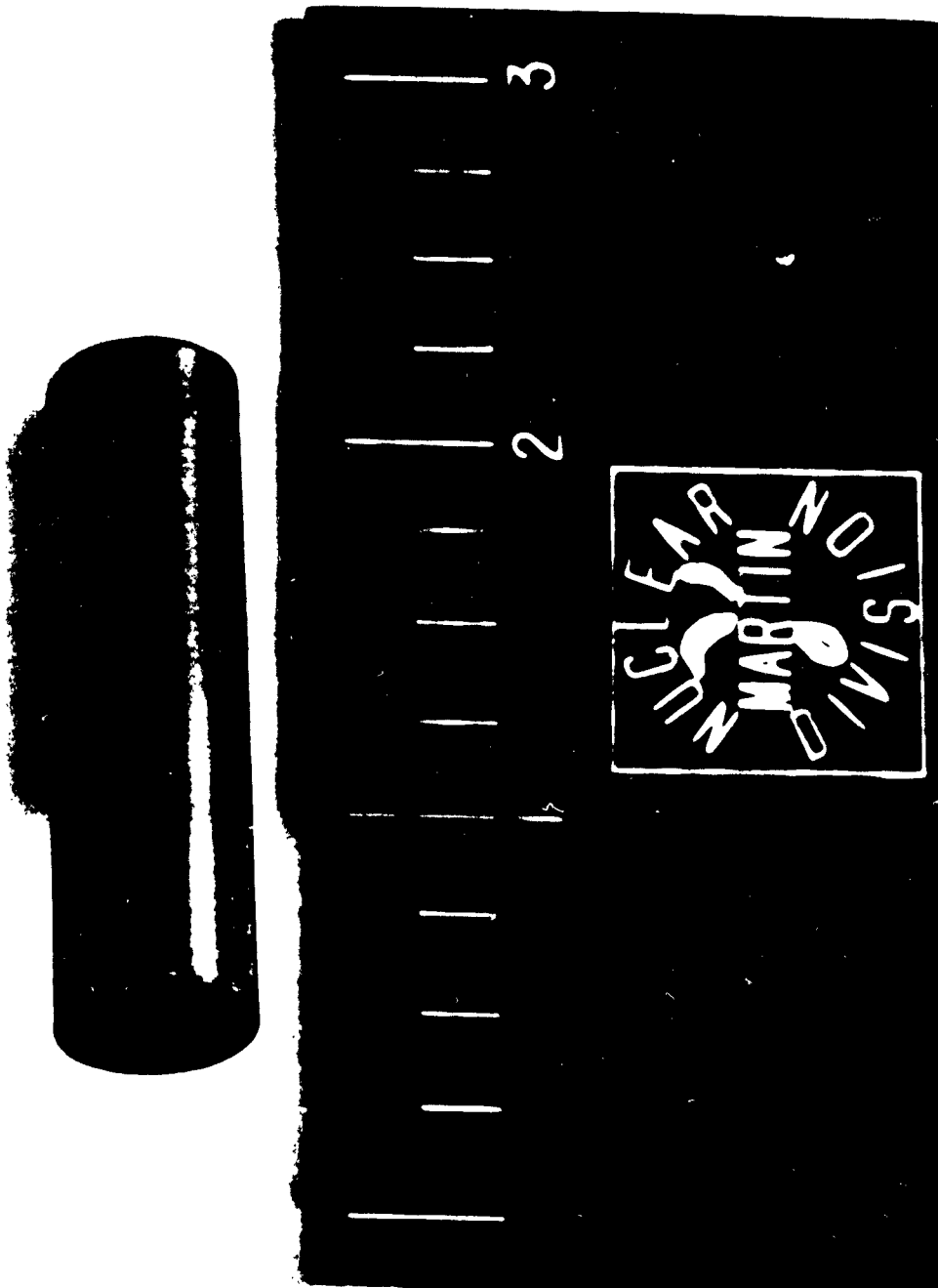


Figure 4

Finished fueled vacuum emitter test element. Central hole is drilled completely through the pellet. Fuel thickness is 0.104 inches and the equivalent U-235 density in the fuel section is 6.75 gm/cc.

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